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Design and Development of DSP Controlled Filament Power Supply for 1 MW, 352.2 MHz Klystron

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Abstract

A digitally controlled current regulated 20 V, 25 A dc power supply employing IGBT based chopper is developed as the filament power supply for 1 MW, 352.2 MHz, Thales make TH 2089 klystron amplifier. The filament of this klystron is floating at cathode voltage of -100 kV dc, hence this power supply is kept on a floated platform and isolated through a suitable HV isolation transformer. Control and protection of this power supply is implemented through Texas make TMS320F2812 digital signal processor (DSP) and fibre optics based optical communication is adopted. Detailed simulation is carried out and a close match between simulated and experimental results was obtained, which are presented in this paper. The long term output current stability and peak to peak output current ripple of this power supply are found to be below 0.5 %

INTRODUCTION

A dc chopper based current regulated 20 V, 25 A dc power supply is employed to power the filament of Thales make TH 2089, 1 MW, 352.2 MHz klystron amplifier.

This power supply is floating at cathode voltage of -100 kV, dc. In fact, the filament of TH 2089 can be powered by either ac or dc source. However, if filament is powered by ac, there is always some residual ac magnetic field in the cathode-anode and input cavity region which causes the phase modulation of RF output and degrade the RF output spectrum [1]. Hence dc filament power supply is adopted. Again, the operating filament current needs to be set carefully. If filament current is too low, it leads to field emission, which is bad for klystron life and if it is too high, it increases the rate of evaporation of Barium from cathode, which can contaminate the gun structure thereby reducing the break down capability of klystron amplifier. The filament resistance of TH 2089 klystron amplifier is 0.1 Ω in cold condition and 0.8 Ω in hot condition [2]. Hence it is necessary to limit the filament surge current especially in cold condition as the high value of surge current may create hot spots in the filament which may further result in it's catastrophic failure. The filament power supply employed in TH 2089 klystron amplifier is operated in slow start mode for 15 minutes to limit surge current to a maximum of 25 A.

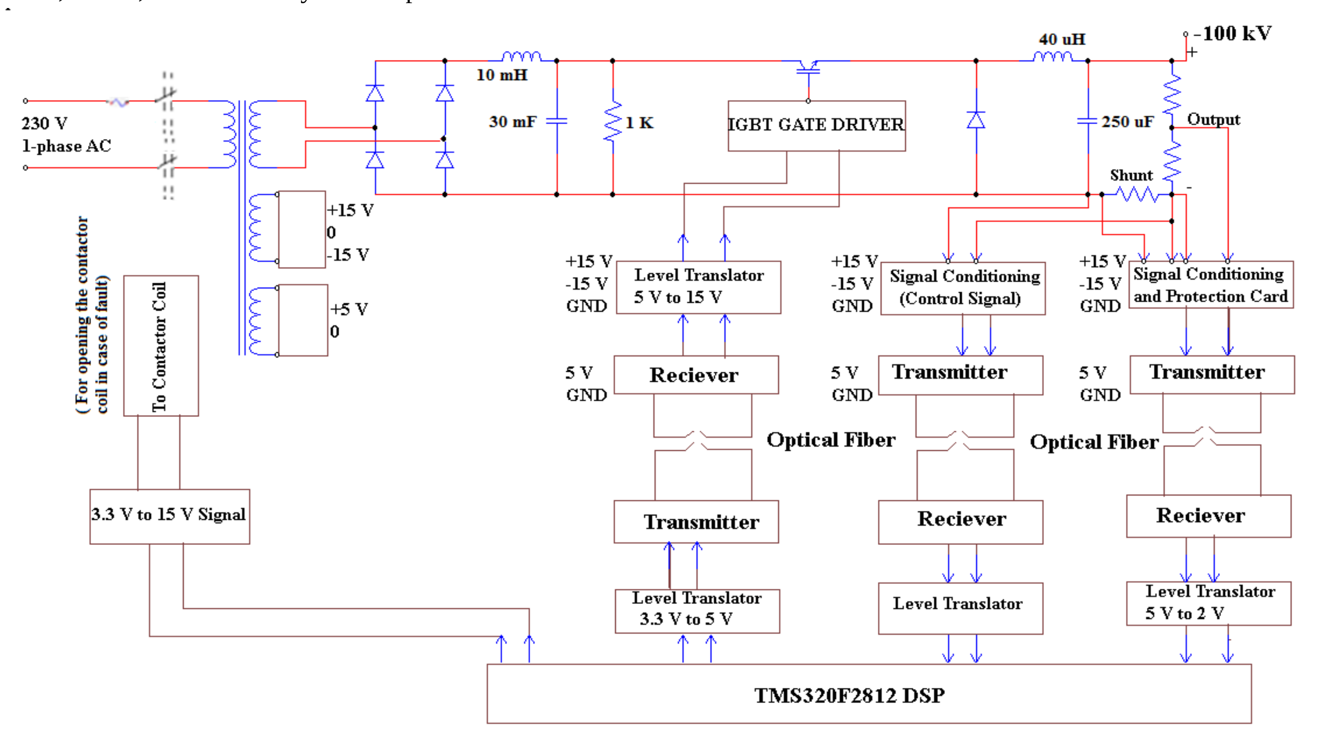


Figure 1: Schematic diagram of filament power supply

The soft start, control and protection of the power supply is implemented through TMS320F2812 DSP. Various issues related to the design and development of this power supply are addressed in this paper.

SCHEME

The design of the filament power supply is based on the principle of chopper control at the secondary side of the transformer as shown in Figure 1. As the filament of the klystron is floating at cathode voltage of -100 kV dc, to isolate the filament power supply from input, a 150 kV isolation transformer is employed. This transformer contains two additional auxiliary windings to provide ±15 V and +5 V control power supplies. The single phase input is applied at the primary of the step down isolation transformer and it's secondary output is rectified, filtered and regulated through an IGBT based buck converter operating at 20 kHz. The isolation transformer is designed to minimize the inter-winding capacitance less than 100 pF and leakage current less than 50 μA. PSPICE simulation of the power circuit is carried out and simulated waveform showing output filter inductor current and output ripple current is presented in Figure 2.

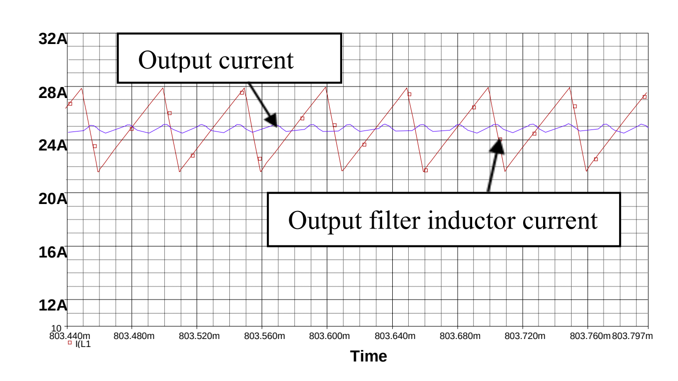


Figure 2: Simulated waveform of output filter inductor current and output current

Fiber Optics based Communication

Fiber optics based communication has been adopted to provide the isolation between the controller DSP and power circuit of this power supply which is floating at -100 kV. Three separate transmitter-receiver channels have been incorporated. First analog optical channel is used to transmit analog feedback signal to the controller DSP. The analog channel employs analog transmitter-receiver set (SFH 756 - SFH 350) with proper optical feedback. The feedback is necessary to maintain linearity across the analog optical channel. This is shown in fig. 3. The second digital optical channel based on HFBR 1521 and HFBR 2521 has been used for transmitting the fault signal to DSP while the third digital channel has been used for transmitting the PWM signal from DSP to the IGBT switch of the power circuit. This transmission is shown in figure 4 and figure 5.

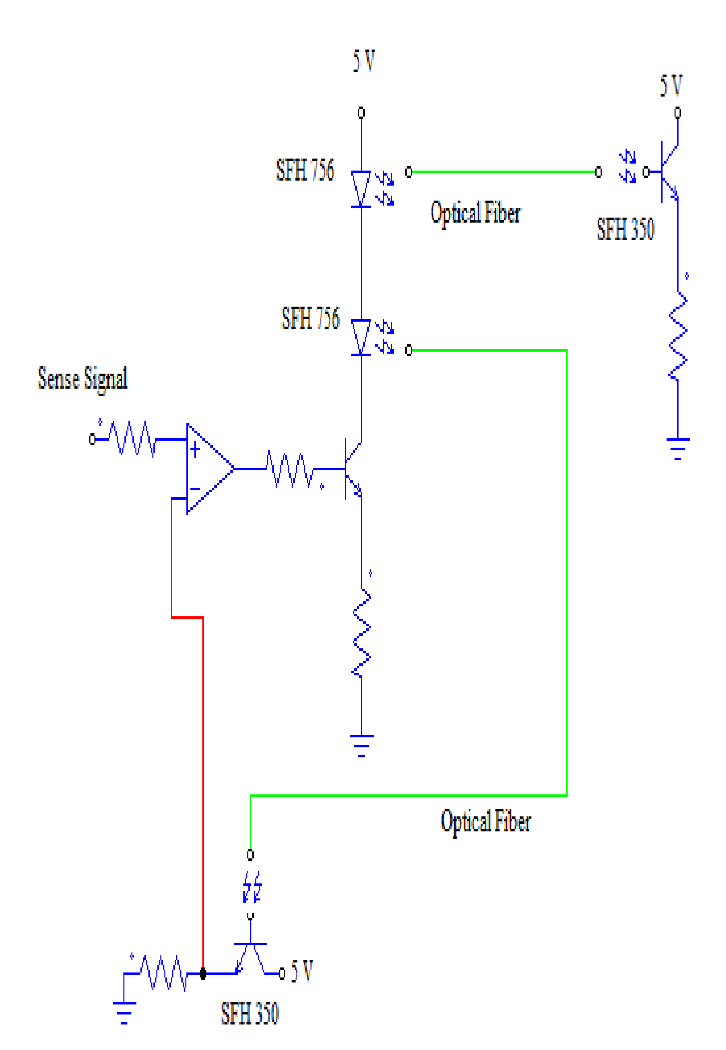


Figure 3: Transmission of analog sense signal through analog transmitter (SFH 756) and receiver (SFH 350) set.

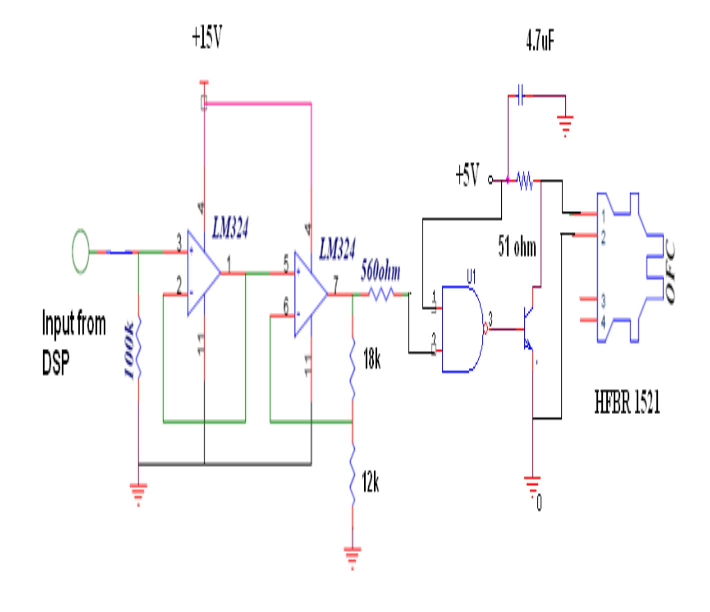


Figure 4: OFC Transmitter with 2V to 5V level shifter for transmitting signal from DSP

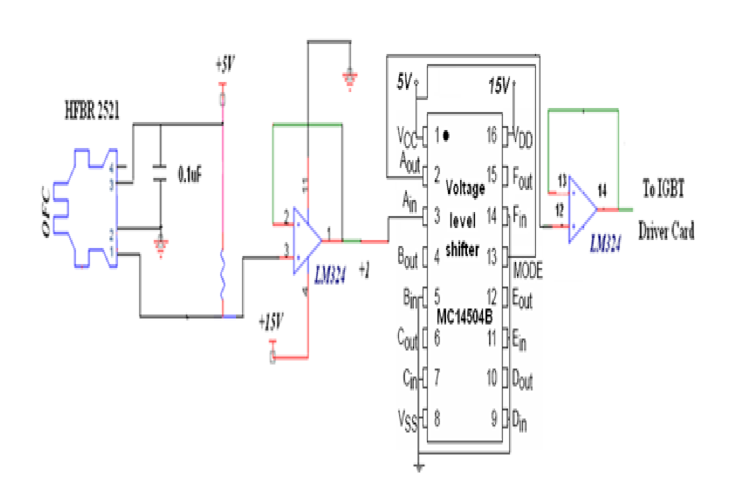


Figure 5: OFC Receiver with 5V to 15V level shifter for IGBT driver card

DSP based control and Protection

The control and protection of filament power supply is implemented through TMS320F2812 DSP. Output current feedback is taken through a shunt and after proper signal conditioning, it is transmitted to the controller. The DSP implements a digital PI feedback controller using an integrated 12-bit A/D converter to read the feedback current and then directs pulse-width-modulated gate signal to IGBT through its driver and thus regulates the output current within 0.5 % for possible input and output variations. The flowchart for the digital PI controller is shown in Figure 6. At the start of each sampling period, there is a 2µs delay before taking the analog to digital conversion. Because the sampling and PWM switching frequency are the same and their periods are synchronous, the start of the sampling and switching periods happened at the same time. The switching action of the IGBT in the buck converter may produce a glitch in the converter output voltage which can be measured by the A/D converter. Measurement of this glitch will produce oscillation in the duty cycle calculated by the digital controller. The sample is taken after the start of the switching period instead to avoid sampling the switching glitches. We have a reference signal corresponding to 20 V output of the filament power supply against which the current value of the power supply output is compared. When the absolute value of the error of the k_{th} sample *e[k]* is less than a defined value *ε*, the converter is considered to be operating in steady state. The controller is applied in steady state to reduce oscillation of the duty cycle. The duty cycle is updated according to the flow chart. After updating the new duty cycle, and the error of the $(k\text{-}1)_{th}$ sample, the interrupt subroutine returned to the main program and waited for a request for the next interrupt.

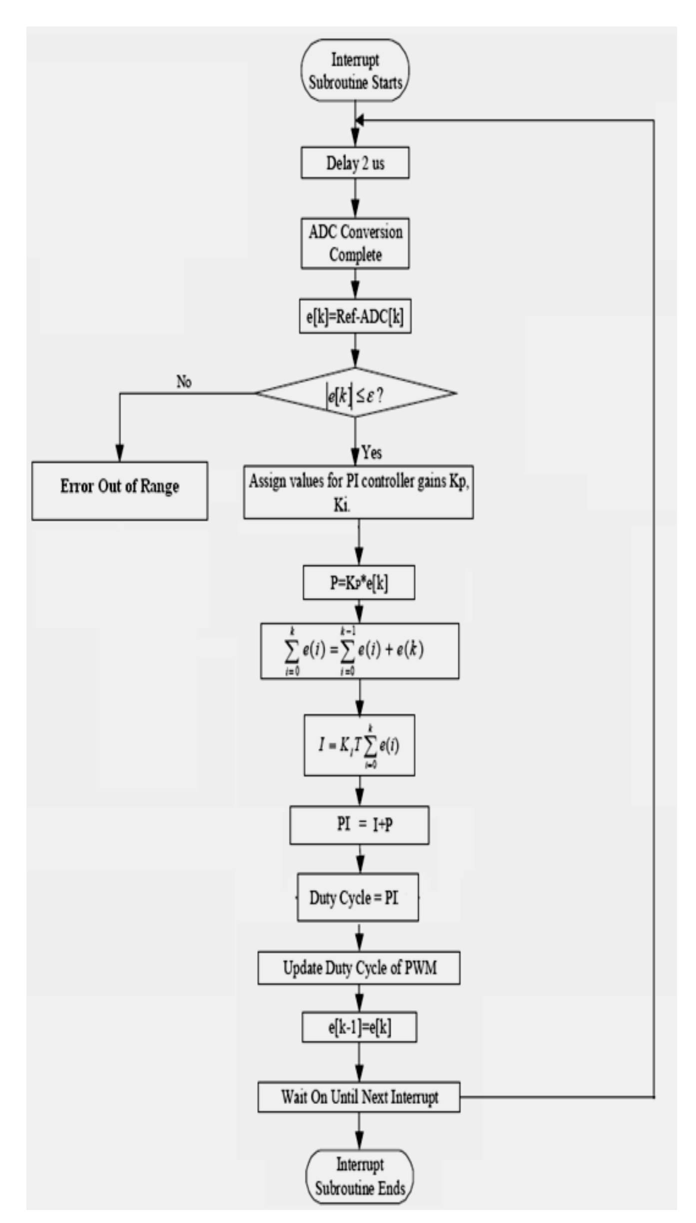


Figure 6: Flowchart for the digital controller

This power supply is initially operated in slow start mode by duty cycle control of the IGBT. Over voltage, over current and under current protections are incorporated in this power supply. In case of fault, the DSP removes the gate pulses to IGBT and simultaneously trips the input contactor to switch OFF the power supply. The fault signal is also used for indication and interlocking. The photograph of the fabricated filament power supply is shown in Figure 7.

EXPERIMENTAL RESULTS

The filament power supply is tested with dummy load. Current regulation achieved is better than ± 0.5% for line variation of ± 10 %. The PWM pulse generated from DSP with 80% duty cycle is shown in Figure 8. Output filter inductor current and output current waveforms are shown in Figure 9 and Figure 10 respectively.

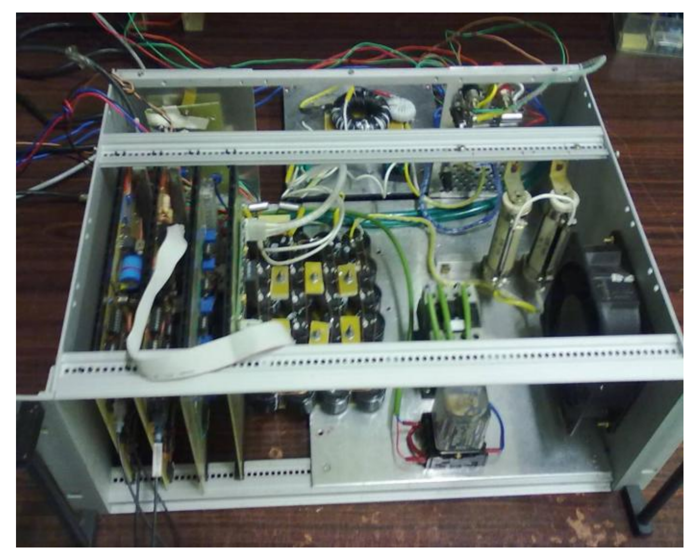


Figure 7: Photograph of the filament power supply

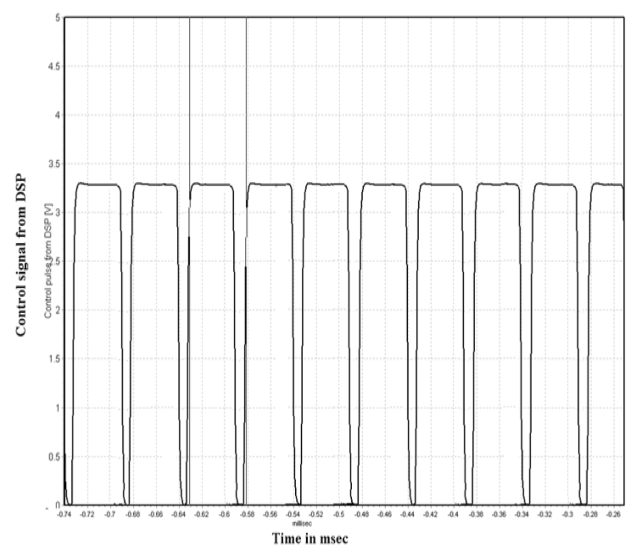


Figure 8: PWM output from the DSP

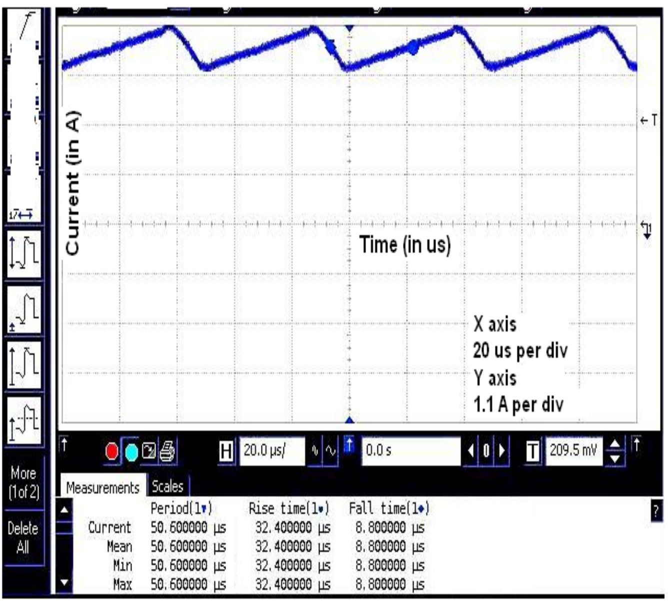


Figure 9: Current flowing through the output inductor

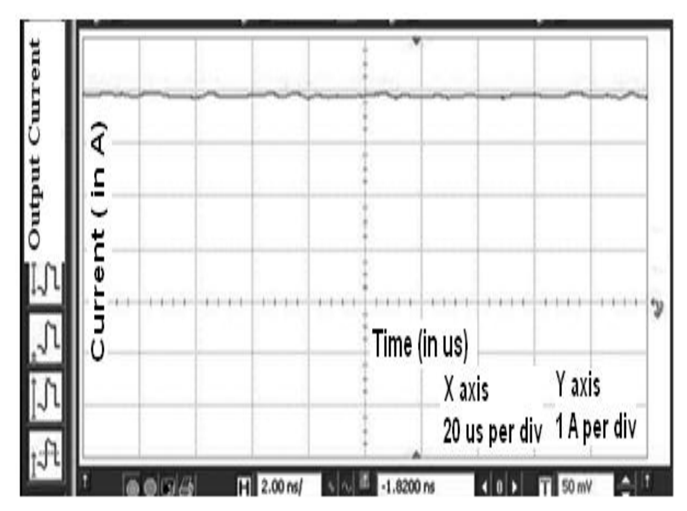


Figure 10: Output current

CONCLUSION

A current regulated 20 V, 25 A dc power supply employing IGBT based buck converter is designed, fabricated and tested as the filament power supply of Thales make TH 2089 klystron amplifier. This supply minimizes the possibility of phase modulation of RF output. The control and protection of this filament power supply is implemented through a DSP. Detailed simulation of the power circuit of the power supply is carried out and a close match between simulated and experimental results is obtained. Long term current stability as well as output current ripple of this power supply are found to be below 0.5%.

REFERENCES

[1] R. F. Koontz, "Anomalous electron loading in SLAC 5045 klystron and relativistic klystron input cavities," *SLAC-PUB-4S67*, March 1989

[2] *TH 2089* klystron data sheet